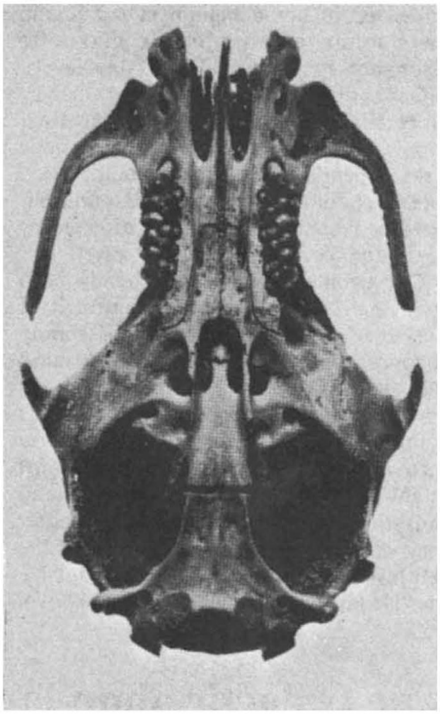
which the electrons are excited and Thiry *et al.* assume that excitation occurs into a free electron final state band. This procedure has previously been shown to give remarkably accurate results for the occupied states of some metals by Stohr *et al.* (*Phys. Rev. B* 17, 587; 1978). Eastman's group makes use of the calculated electron states and both groups obtain very good agreement with theoretical predictions of the band structure of copper. Electron mean free paths determined from the experiments confirm the well known surface sensitivity of photoelectron spectroscopy particularly for excitation wavelengths below about 500 Å. Thiry *et al.* observe excited 3d hole lifetimes in copper which are in good agreement with the estimates of Pendry and Titterington, and further show the great importance of having a high angular resolution in the experiments.

These experiments again underline the power of angle-resolved photoemission coupled to a synchrotron radiation source as an accurate probe of electron states in solids. Studies similar to those described for copper, above, have also been conducted on nickel (Eastman, Himpsel & Knapp *Phys. Rev. Lett.* **40**, 1514; 1978) and the ferromagnetic exchange splitting accurately established. Coupled to other variations of the photoemission technique such as photoelectron diffraction (see *News and Views*, **279**, 755; 1979), which enable the locations of atoms near a solid surface to be established, an active and rewarding future in this area is certain, particularly as new dedicated synchrotron radiation sources such as the one at Daresbury in the United Kingdom become operational. These new methods will lead to a greater understanding of metals, alloys, semiconductors and insulators and will undoubtedly be important in probing areas such as surface reactions, oxidation of solids, and corrosion. □

# The black rat in Britain

THE finding by archaeologists of remains of *Rattus rattus* in a filled-in Roman well in York in the north of England, suggests that the black rat was present in Britain several centuries earlier than had previously been supposed. The finds, which are discussed by James Rackham of the University of Durham in the latest issue of *Antiquity* (**53**, 112; 1979), lend support to the idea that epidemics of plague occurred in Britain well before the infamous Black Death of the Middle Ages, and may even have been common in Roman times.

Historians have assumed that the black rat — to be distinguished from its close relative the brown or Norway rat, *Rattus norvegicus* — was not introduced into Britain until the Norman period, when returning Crusader ships brought it from the Near East. The many contemporary



Black rat skull found in a Roman well in York.

records of 'plague' in Anglo-Saxon Britain in the 6th and 7th centuries AD have been either ignored or explained away as outbreaks of smallpox or other virulent diseases.

There is no doubt that the high mortalities in the early centuries AD were often caused by a multitude of diseases, of which smallpox was certainly one. But it does not seem likely that Roman Britain would have completely escaped the plague epidemics that swept around the Mediterranean area and across Europe between the 1st and 6th centuries AD. The most serious of these pandemics — without doubt of bubonic plague — began in about AD 540 during Justinian's reign and spread from the Mediterranean up into central Gaul and Germany, and almost certainly would have reached the British Isles.

Plague usually spread from one coastal port to another because infected black rats would find their way on to and off ships. As there was extensive sea trading between Roman Britain and the rest of the Empire the introduction of rats into a British port could easily have happened. York was a thriving Roman administrative and trading centre. Like other large towns of the period, it was a port of call for supplies from many parts of Europe — indeed it is known to have had strong connections with Bordeaux and Rhineland. So it is not surprising that the black rat slipped into the town one day.

The rat remains recovered from the Roman well represent at least two individuals and include a well-preserved skull, a complete mandible with all its teeth, fragments of maxilla and premaxilla, and a cervical vertebra. The wall was timber-lined and was probably built in the late 2nd or early 3rd century and was then filled-in towards the end of the 4th century AD. During excavation careful checks were made to exclude the possibility that the rats had burrowed into the well after it had been sealed. This, and other evidence from Roman objects found in association with the rat remains and radiocarbon determinations suggest a 4th, or at the latest a 5th century date for the specimens.

These finds of the black rat in Roman Britain lend some support to John Wacher's controversial idea that plague led to the downfall of Romano-British towns in the 5th and 6th centuries AD at the time the Western Roman Empire was disintegrating. Wacher has suggested (*The Towns of Roman Britain*, Batsford 1974; *Roman Britain*, Dent 1978) that the depopulation of these towns was caused by epidemics striking an already threatened Romano-British culture. As economic decline set in, so the way was made easy for the conquering Anglo-Saxons and the start of the Dark Ages. S.B.

# Quest for superfluid hydrogen

*from P. V.E. McClintock*

THE possibility of preparing monatomic hydrogen ($H_1$) at high densities seems to have come a stage closer with three papers published in recent issues of *Physical Review Letters*. Two separate research groups have simultaneously reported the first observations of magnetic resonance from $H_1$ held at liquid helium temperatures: Crampton, Greytak, Kleppner, Phillips, Smith and Weinrib of the Massachusetts Institute of Technology (*Phys. Rev. Lett.* **42**, 1039; 1979); and Hardy, Berlinsky and Whitehead of the University of British Columbia, Vancouver (*op. cit.*, 1042). On a slightly different tack, Guyer and Miller of the University of Massachusetts, Amherst, have calculated how $H_1$ may be expected to interact with a helium coating on the wall of its containing vessel (*op. cit.*, 1754).

The notion of monatomic hydrogen has been around for quite a long time. Hecht seems to have been the first to point out (*Physica* **25**, 1159; 1959) that $H_1$ at low temperatures and high densities might be expected to display quantum properties on a grand scale and, in particular, that it might undergo a superfluid transition rather like that of liquid $^4$He. These possibilities rest on the observation that, although a pair of hydrogen atoms with oppositely directed electron spins attract each other and form a molecule of $H_2$, a pair of atoms with parallel electron spins (in a so-called triplet state) experience a repulsive interaction. This means that a gas of spin-aligned $H_1$ atoms could be cooled to very low temperatures, even at a high density, without ever condensing into a

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liquid, let alone solidifying, as do all other materials except helium (which stays liquid to absolute zero). The weak interaction forces between the atoms, coupled with the very low atomic mass, provide the ideal recipe for quantal behaviour: since the atomic mass is only a quarter that of $^4$He, one may guess that the quantum properties of $H_1$ gas would be even more extreme than those of liquid helium.

Similar ideas can be applied to monatomic deuterim ($D_1$) and tritium ($T_1$), the heavier isotopes of hydrogen. Some interesting differences in their properties may be anticipated, however, because $H_1$ and $T_1$, each containing an even number of fundamental particles, are bosons, while $D_1$, with an odd number, is a fermion. Thus $D_1$ might perhaps be expected to behave rather like liquid $^3$He, whereas $H_1$ and $T_1$ might each be expected to behave more in the manner of liquid $^4$He. As gases, however, they would probably all have properties closer to those of ideal Fermi-Dirac and Bose-Einstein gases than the heliums. Such questions are of fundamental interest and importance for quantum mechanics and statistical mechanics, and this is a large part of the reason for the intense interest in seeing whether dense monatomic hydrogen can be made a reality on a macroscopic scale.

Although there has been a good deal of theoretical work on spin aligned hydrogen, with detailed predictions for many of its properties, relevant experiments have been somewhat thinner on the ground. The fundamental practical problem is, of course, to find a way of stabilising the $H_1$ gas against recombination to form $H_2$ molecules. The basic idea is to use a suitable container placed in an intense uniform magnetic field and held at a very low temperature. The field will induce a splitting in the ground state energy levels of the $H_1$ atom, depending on whether its electronic spin is pointing with or against the field; and it is hoped that the low temperature will ensure that the atom stays in the lowest level, that is, spin-aligned. It is believed that a field of 10 T and a temperautre of about 0.1 K might provide the necessary conditions for stable confinement of the $H_1$ gas. These conditions are realisable using existing cryogenic technology.

Before a full scale apparatus can be designed, however, it is necessary to obtain information about the properties of individual $H_1$ atoms at low temperatures and, in particular, about any mechanisms able to cause the spin flips which would rapidly lead to recombination to ordinary $H_2$. That is why the work reported from MIT and UBC is so important. Both groups have succeeded in conducting $H_1$ atoms down to experimental chambers immersed in liquid helium at 4.2 K and have managed to observe magnetic resonance between the hyperfine levels. This has now opened the way for further, more detailed, studies aimed at measuring, for example, the temperature and magnetic field dependences of the recombination rate. It should also be possible to find out how the recombination rate is affected by the material of the walls of the vessel.

One problem which had already been foreseen is that magnetic impurities inevitably present in the walls may encourage spin flips. A possible way round this difficulty would be to coat the walls with a layer of superfluid $^4$He, which is completely non-magnetic. The question then arises as to whether the $H_1$ atoms might be able to enter the $^4$He layer, and thus still be able to reach the walls; whether they will be trapped on the surface of the $^4$He layer; or whether they will stay outside the $^4$He layer altogether. Miller has shown (*Phys. Rev.* **B18**, 4730; 1978) that the $H_1$ is actually totally insoluble in liquid $^4$He; Guyer and Miller now demonstrate that there will, in fact, be a shallow physiadsorbed state for $H_1$ just outside the $^4$He layer, but that this state will not be heavily populated. They comment that $^3$He impurities in the $^4$He could give rise to difficulties since these, too, will congregate at the surface. This potential problem is easily circumvented however, because techniques have recently become available for the virtually complete removal of the $2 \times 10^{-7}$ parts of $^3$He found in commercial $^4$He. So it looks very much as though a coating of isotopically pure superfluid $^4$He will constitute an effective method for preventing wall-induced spin-flip processes.

Clearly, there is still a long way to go before superfluid hydrogen becomes a reality, but the present flourish of activity aimed in this general direction is most encouraging. □

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# The Galactic abundance gradient

*from M.G. Edmunds*

A CONSISTENT picture is at last beginning to emerge of the behaviour of the overall abundance of the elements, relative to hydrogen, as a function of position in our Galaxy. To a good approximation we can regard most elements heavier than helium as being produced in constant relative amounts during a single process — supernova nucleosynthesis — and the abundance of any one element is a fair indicator of the abundances of all the elements. There are of course a few exceptions, elements which are produced during quiescent stellar evolution such as nitrogen, but the majority are believed to come from supernovae. We can regard the Galaxy as a two-component system, made up of a disk of stars and gas, surrounded by a more-or-less spherical halo of old stars and globular star clusters. The pattern of the variation in abundance with distance from the Galactic centre in both disk and halo has become clearer with the publication of several papers over the past year.

K.A. James (*Astrophys. J. Suppl.* **39**, 135; 1979) has used narrow and wide band photometry to estimate metal abundance (anything heavier than helium) in a sample of giant stars and about 40 star clusters in the disk. Photometry can yield an abundance for a star because the strength of the absorption lines in the spectrum of the star's atmosphere is dependent on abundance, and the lines are not evenly distributed in wavelength. Thus a star with high abundances will emit less light in certain regions of its spectrum (particularly at short optical wavelengths), and more light in other regions, than will a metal-poor star. The differences are large enough to be detected by photometry of selected wavelength bands. The study of clusters is particularly useful because their distances can be estimated with reasonable accuracy, something that is very difficult to do for individual stars.

James finds there there is a distinct gradient of abundance decreasing outwards from the region of the Sun (10 kpc from the centre) to as far as he has measured at 14 kpc, although inwards towards the Galactic centre (from 10 kpc to 8 kpc) he claims to find little or no gradient. But his results are open to reinterpretation, and it may simply be that the classical notation for presenting abundances (as the logarithm of the quotient of the metal abundance relative to hydrogen in a star divided by the same thing for the Sun) may have obscured the actual trend. If James's data are replotted on a linear abundance scale, rather than a logarithmic one, then a simple straight line fits beautifully within the error bar in the plot of abundance against distance from the centre, both inside and outside the position of the Sun.

This therefore implies a simple linear abundance decrease in going from 8 to 14 kpc, a result which is in nice agreement with the indications of a linear abundance gradient in the interstellar material, deduced by observation of emission spectra of HII regions. There is much scatter in these derived nebular abundances, although this is probably mainly due to errors in observation and analysis, and it had originally been thought that this latter gradient was much steeper. But a reanalysis of the spectra assuming that temperature fluctuations in the nebulae are not important (as seems reasonable from recent theoretical modelling) gives a gradient in oxygen

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